Effect of Surface Waviness on PMMA by CO₂ Laser Micro Milling

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Abstract—The engraving or embossing on any product is very common operation in manufacturing. The process of laser is very popular for marking on different kind of surfaces may be with metals or non metals. The very fine material removed during operation may lead to affect the surface quality, which is very significant from the aspect of quality of product. The waviness occurrence due to movement of laser head is quite obvious as the material gets evaporated and settled back may be of very minute quantity. Hence the surface waviness is an important parameter in estimating quality of machining. The present work, deals with micro milling of the polymethyl methacrylate (PMMA) considering the capacity of available capacity of laser machine set up and class of absorptivity of material. The present work deals with the study of waviness with variation in speed and power within min to max available range of selected machine. The results are analyzed based on Anova for finding the contribution of speed and power on waviness.

Keywords—CO₂ Laser, Engraving, Surface Waviness, PMMA.

I. INTRODUCTION

The word laser is an acronym for “light amplification by the stimulated emission of radiation,” It has been true throughout history that every time mankind has mastered a new form of energy there has been a significant, if not massive; step forward in our quality of life. Due to discovery of the laser in 1960, Optical energy in large quantities and in a controlled from is now available as a new form of energy the civilized world, it may be applied to any process by understanding the mechanism of requirement [1]. The low power CO₂ laser has been found feasible for non metallic material for other than marking operations such as engraving for low material removal applications [2]. The cut obtained by set of various parameters of machine can be estimated by predictive models based on experimental data. The amount of energy used in acual cutting and amount of energy consumed as loss establishes efficiency terms for a particular setup. [3] The laser cutting is a popular process in several manufacturing industries due to their ultra flexibility of cutting condition for high quality end product because of small heat affected zone and non contact tool. However power used for melting material may create problems like kerf width etc and hampers the quality [4]. The cutting and grooving also investigated in light of theoretical expressions and it is validated with experimental observations for better predictions [5]. The present work deals with quality of surface generated and the effect of parameters which may be controlled for required acceptance.

II. EXPERIMENTAL

The experimentations were planned with the selection of PMMA material as its absorptivity is high and reveals clear cut, it also possesses attractiveness, electrical insulation, Non-toxic, and Crack resistance which has been reported in literature by many of investigators [5,6,7]. The parameters (i) power which is responsible for transferring energy and (ii) traverse speed which is responsible for rate of energy transfer are varied from their minimum to maximum range i.e 0 to 25 Watt and 0 to 42 inch per second. Each set of combination of parameters is responsible to evaporate certain amount of material. However it may be possible that a volume of material may settle back due to incomplete evaporation or improper removal of evaporated material.

A Mercury II laser pro 25W, a commercially designed carbon dioxide laser coupled with precision computer-controlled X–Y table, was used as a setup. The machined has capability to cut the material by vector and raster mode. The present work was attempted using raster option as it involves micro milling, while the vector mode is mainly used for cutting. The coral draw software was used to build a engraving area and the intensity of cutting was set as 600 dpi(dot per inch). In order to take some finite observations it was decided to take 25 set of reading considering variation in speed as 5%, 25%, 50%, 75%, 100% of max speed(42 ips), and variation in power 5%, 25%, 50%, 75%, 100% of max power (25 W). The traverse of laser head was computer controlled in XY direction based on specific print driver. A square geometry of 10×10 mm area was selected on the PMMA plate to mill cavity surface for selected 25 set of readings. The milled plate is shown by Figure 1.

![Fig. 1 Acrylic sheet plate with cavities for 25 set of experiments.](Image)
The micro milled cavities are observed to have some amount of waviness at their base surface which is significant parameter to be focused as the product should offer maximum finish. Normally metal parts are checked with their surface roughness (Ra) as a measure of finish quality. However for the present case the finish is of coarser in nature, hence milled area are focused with coordinates to achieve peaks and valleys. The Roland make Picza 40, Needle scanner (with an accuracy of 20 μm) was used as coordinate measuring machine to measure Z values at the pitch of 1 mm in X and Y directions. The setup of Needle scanner with its setting snap is shown in Figure 2.

The point cloud generated by this methodology can be handled by Dr Picza software which is supplied with machine setup to edit/amend data and converting it to in to appropriate format for further processing in the form DXF, IGES, VRML or Point cloud data. The snap of point cloud output and result of such data visualized in spread sheet after exporting it is shown by Figure 3.

To analyze the heights obtained through coordinate point in terms of Z by considering cavity in XY the concept of Arithmetic average height (Ra) is applied to find waviness in milled surface. The arithmetic average height parameter also known as the center line average (CLA) is most universally used roughness parameter for general quality control. It is defined as the average absolute deviation of the roughness irregularities from the mean line over on sampling length. This parameter is easy to defined, easy to measure and gives a good general description of height variations as shown in Figure 4. It does not give any information about the wave length and it is not sensitive to small changes in profile. The mathematical definition and the digital implementation of the arithmetic average height parameter are respectively,
III. RESULTS AND DISCUSSIONS

The waviness obtained using analysis of point cloud data for variation of power and speed is shown in Table 1. The variation in its magnitude does not reveals any pattern with variation of single parameter but it may depend on combination of parameters.

<table>
<thead>
<tr>
<th>Power %</th>
<th>100</th>
<th>75</th>
<th>50</th>
<th>25</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed % ↓</td>
<td>5</td>
<td>0.25094</td>
<td>0.12921</td>
<td>0.14261</td>
<td>0.1048</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.01422</td>
<td>0.035883</td>
<td>0.02444</td>
<td>0.01304</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.02762</td>
<td>0.03133</td>
<td>0.018476</td>
<td>0.016445</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.04230</td>
<td>0.025004</td>
<td>0.01682</td>
<td>0.031703</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.03088</td>
<td>0.02037</td>
<td>0.031692</td>
<td>0.01667</td>
</tr>
</tbody>
</table>

The results are analyzed using Analysis of Variance (ANOVA) to estimate quantitatively the relative contribution that each control factor or parameter (A, Speed ~96%;and B, power ~4%) as reported in Figure 5, which makes on the overall measured response. The relative significance of factors is often represented in terms of F-ratio or in percentage contribution.

![Fig. 5 Contribution (%) of Power and Speed for Waviness.](image)

The amount of power rises at constant speed the waviness also increase linearly as of high material removal rate, however the magnitude of waviness is also affected by speed, which is shown in Figure 6., lower the speed, higher the magnitude of waviness which is obvious due to high amount of material evaporation and more problems toward their removal from machine system specially in case of blind cuts and coarser regions. Hence at higher speed waviness reduces as depicted in Figure 7. The small amount of material removal rate leads to provide clear cuts and the evaporated gases can escape without more complexity.

![Fig. 6. Result of power v/s waviness](image)

![Fig. 7 Result of speed v/s waviness](image)

REFERENCES